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[PLATES 36 AND 37.]

# N THE RESTORATION OF CO-ORDINATED MOVEMENTS AFTER NERVE-CROSSING, WITH INTERCHANGE OF FUNCTION OF THE CEREBRAL CORTICAL CENTRES.

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# III. *On the Restoration of Co-ordinated Movements after Nerve-crossing, with Interchange of Function of the Cerebral Cortical Centres.*

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[Plates 36 and 37.]

Contents.



## I. Introduction.

Restoration of voluntary co-ordinated movements after reunion of a divided nerve is well known to occur, but the exact process by which it is brought about is by no means clear. This favourable result might be due to re-establishment of the old paths

for the nervous impulses, or, on the other hand, the phenomenon might be due to the establishment of new paths due to the inevitable imperfect coaptation of the divided nerve ends. Each of the nerve-fibres in a nerve-trunk is supposed to be the path of communication between a central cell and a definite peripheral area. On dividing the nerve-trunk, and reuniting it by suture, it seems to be a difficulty to assume that perfect coaptation has been made of all or even of a majority of the cut fibres. If such an assumption is made, then the difficulty of the problem disappears, but it is clear that an assumption of the kind is unjustifiable.

In a former paper (20)* I showed from experiments on the sciatic nerve in dogs that the progress of recovery is practically the same whether the nerve is reunited by suture as accurately in the old position as possible, or whether the opposite state of matters is ensured by rotating the peripheral segment through a semicircle before reuniting it to the central segment. It is true that the peripheral segment of the nerve undergoes Wallerian degeneration after the act of division, but it is nevertheless still a necessity for the regeneration of the nerve. Taking the view of regeneration advocated by RANVIER (8, 9), it is a necessity only as a guide for the growth of the young sprouting nerve-fibres to the peripheral terminations, supplying these fibres at most with their envelopes (STRŒBE, NOTTHAFT, HOWELL and HUBER). Taking, on the other hand, the view that the peripheral segment regenerates its own young nerve-fibres after the degeneration of the old fibres, which view I prefer (15), then each fibre in the peripheral segment is reproduced from the point of division on to the peripheral ending. In either case careful coaptation of the cut ends of the nerve would seem to be an important element for the re-establishment of the old paths along which nervous impulses were transmitted. If accurate coaptation is impossible, and if the accuracy of coaptation is not an essential condition of restoration of co-ordinated movements, then the explanation of restoration is either that the central ends are endowed with the capacity of finding their proper peripheral ends, or that the nerve-centres are capable of altering their functions in so far that, when brought into connection with new muscular fibres by the alteration of the paths for nervous impulses, they can call forth muscular contractions in the new muscular fibres, so as to cause perfectly co-ordinated movements.

It was thought, when my former experiments were made, that the microscopic appearances of the segment of reunion would decide whether the restoration of function was due to the re-establishment of the old paths or to the formation of new paths. On examination, however, this point was not clearly indicated, as the segment of reunion presented the appearance of a neuroma, the nerve-fibres being greatly convoluted. I therefore conducted several experiments on nerve-crossing, or the division of neighbouring nerves and cross union, in order to determine whether, with absolutely secured alteration of innervation, restoration of voluntary co-ordinated movements could occur.

* The numbers in parentheses refer to the Bibliography, p. 160.

## II. Résumé of Literature.

The first recorded experiment on nerve-crossing was conducted by Flourens (1) as early as 1824. In a cock he cut "the two chief nerves which go from the brachial plexus, the one to the superior aspect and the other to the inferior aspect of the wing." On section of these nerves the wing drooped completely, and its extremity could not be moved at all. He then crossed the nerves, "joining the superior end of the one nerve with the inferior end of the other and *vice versâ*," and maintained them in this position by means of sutures. "At the end of some months the animal had perfectly regained the use of the extremity of its wing, which no longer drooped, and made use of it for flying quite as well as before the experiment." On exposing the nerves which had been crossed, he found that the position in which he had placed them had been maintained. He irritated the exposed nerves above, below, and on the seat of reunion, and found that irritability and conductivity were present; but he does not make it clear whether the point of reunion (point grossi de la réunion) was one which embraced all four ends, or if there was a separate enlargement at the two seats of union.

The objections which have been urged against this experiment are that no sufficient precautions were taken to prevent confluent union of all four ends, and that the nerves might therefore have reunited in their normal continuity in the common cicatrix; that no sufficient description is given of the return of voluntary co-ördinated motion to enable the reader to judge if such had been restored (Schiff); and, by Cunningham, that the recovery of function might have been due to the tensors of patagium, whose supply remained intact. We have, however, although the description is brief, the statement of Flourens that the wing was used for flying as well as before the experiment. That the conductivity of the nerves had been restored, and the crossing effective would appear from his statement, "when I pinched the superior nerve above the point of reunion, it was the muscles of the inferior aspect which contracted; and it was, on the contrary, the muscles of the superior aspect of the wing which contracted when I pinched the inferior nerve, likewise above the point of reunion."

Some years later it occurred to Schwann (2) that it was improbable after division and reunion of a nerve, that the corresponding ends of the nerve fibres had united as before the division, and he thought that probably many of the sensory fibres might be brought to lie opposite motor fibres and unite with them. With the perfect restoration of function which ensued after reunion of the nerve, Schwann thought that possibly some of the sensory fibres became paths for transmission of impulses to muscles. To test this, he divided in a frog both sciatic nerves, and after reunion and perfect restoration of function, he exposed the roots of the sciatic nerves, and irritated the posterior roots after severing them from the spinal cord, to ascertain if thereby muscular contractions could be evoked. But the result was negative, as

no muscular contractions resulted, and on irritating the anterior roots the normal results followed. This experiment was also performed by STEINRÜCK.

Following these workers came BIDDER (3), GLUGE and THIERNESSE (4, 6), and PHILIPEAUX and VULPIAN (5), who experimented on the crossing of functionally different nerves to see if union could be effected between such. BIDDER united the central segment of the divided hypoglossal to the peripheral segment of the divided lingual, and *vice versâ*. In those cases in which he found a partial restitution of motion and contraction of the muscles on irritating the central segment of the hypoglossal, he found that there had been a certain amount of reunion of the two segments of the hypoglossal, and concluded that a functional union between sensory and motor nerves was unlikely. GLUGE and THIERNESSE performed the same experiment, and found no physiological union of the two nerves, and concluded that such was not possible. PHILIPEAUX and VULPIAN crossed the central segment of the vagus with the peripheral segment of the hypoglossal nerve, and obtained contractions in the muscles of the tongue on irritating the vagus.

All these experimenters aimed at testing the possibility of nerves of different functions uniting, and changing their function, their point being to find if the nerve current in the two was different or the same. They did not evidently require the return of voluntary function, but would have been content to have found acquired conductivity to electrical stimuli.

RAWA (10), in 1885, published *in extenso* the results of his experiments which had appeared two years previously in abstract. There are two parts to his research, namely, cross union of nerves of the same function but of different distributions, and cross union of nerves of different functions. In the former part the nerves which he chose to cross were the posterior tibial and the peroneal, aiming thus at a crossing of the nerve which supplies in the hind-limb the flexors of the foot with that which supplies the extensors. Experiencing the difficulty of getting the two junctions to heal separately, and not in a common cicatrix, the method by which he chose to eliminate this source of error was to make one cross only, and to freely excise the uncrossed central and peripheral ends. This method, however, can give only defective results or results difficult to interpret, as the animal under such circumstances cannot be expected to make a perfect recovery, and with the restoration of function of the crossed nerve, the formation of a contracture could only be expected, a contracture which would mask any voluntary efforts at motion. He, however, describes in several instances return of flexion where the central end of the peroneal nerve was crossed with the peripheral end of the posterior tibial, and of extension where the central end of the posterior tibial was united to the peripheral end of the peroneal, and on the crossed nerve being exposed, irritation of the central segment resulted in contraction of the muscles supplied by the peripheral segment of the crossed nerve. He points out that when an extensor nerve was crossed with a flexor nerve, the change of flexion and extension did not ensue at once, but slowly, and in several

instances he determined that the return of voluntary movements did not coincide with the date of reunion, but was effected at a much later date. He concludes, 1st, That on union of the peripheral end of a motor nerve with the central end of another, the function of those muscles which the former supplies becomes restored; and 2nd, That the direction of the voluntary motor impulses which emanate from the centre can be altered at will, and that they will always accommodate themselves to their peripheral end-organs.

In the second part of his research, he crossed the vagus with the hypoglossal, usually only one central end being united to one peripheral end, the remaining two ends being excised to the extent of 1 to $2\frac{1}{2}$ centims. In those cases in which he united the central end of the hypoglossal to the peripheral end of the vagus, after some months he divided the vagus of the opposite side in order to ascertain if the function of the crossed vagus was carried on through the hypoglossal; and in the cases in which he had crossed the central segment of the vagus with the peripheral end of the hypoglossal, after some months the opposite hypoglossal was cut. In a large number of experiments in which the former operation was carried out, the great majority of the animals succumbed very soon after division of the vagus of the opposite side, so as to make it clear that no adequate vagus function was supplied through the hypoglossal, but in a few cases the animals lived long enough, and the effects of the division of the second vagus were so slight as to lead RAWA to conclude that the crossed hypoglosso-vagus was transmitting effective impulses. Similarly in the cases of union of the central end of the vagus to the peripheral of the hypoglossal, he concludes that impulses transmitted through this crossed nerve can call forth normal movements of the tongue. He concludes that by a successful union of nerves of different function, the peripheral organs retain as before all their requirements. The explanation which he gives of his results is that the nerve-centres can innervate organs which do not belong to them, as soon as they are united to them by nerve conductors, and, on the contrary, that peripheral organs can receive impulses from nerve-centres to whose innervation they do not belong.

The publication of these results induced SCHIFF (11) to commence a series of experiments to test the matter. He expresses surprise at RAWA's results, and indicates that movements observed in the affected foot may have been erroneously regarded as voluntary, when they were really merely passive movements, produced by movement at the knee-joint. This, as already indicated, is a possibility considering that in RAWA's experiments only one cross was made, the result being contracture of one of the opposing groups of muscles. SCHIFF, therefore, thought to settle the matter by crossing two efferent nerves which control movements of a different type, *e.g.*, one voluntary motion and the other rhythmic motion. He, therefore, united the peripheral end of the hypoglossal with the central end of the vagus, making only one cross and excising widely the other two ends. If the peripheral organ determined the kind of movements which returned, then SCHIFF expected to find some

return of normal motion in the paralysed moiety of the tongue, but if, on the contrary, it was the central apparatus which determined the character of the movement in the peripheral organ, then he expected to find movements of a rhythmic type develop in the tongue. As a matter of fact he found after four months that movements had developed on the surface and border of the tongue which could not be taken for rudimentary or returning voluntary movements.

REICHERT (12), who examined the animals at six months for SCHIFF, reports that in the affected moiety of the tongue there was no return of voluntary movements, but that in their place were developed circumscribed areas of rhythmic movements between which, and the movements of respiration, there was an unmistakable relationship. He also described a series of vermicular movements occurring in the posterior and middle thirds of the tongue during deglutition, and the same during vomiting. SCHIFF and REICHERT, therefore, both conclude their papers by combating RAWA'S conclusions, SCHIFF holding, on the other hand, that it is the nerve centres which determine the movements which are produced at the periphery in a crossed nerve, and that the peripheral segment only determines the locality in which these specific movements are manifested. "Mais ni l'instinct, ni le besoin, ni la volonté, ni la prétendue loi de l'harmonie ne peuvent changer directement les mouvements prédéterminés par le mécanisme de l'organe nerveux central."

The next contribution to the subject was made by STEFANI (13), whose experiments point to the same conclusions as those of RAWA, but as they are more convincing, and as they resemble my own experiments, I shall quote them more in detail. He gives two sets of experiments in dogs, viz. :—one, an example of four similar in which he crossed the median with the musculo-spiral, and three, in one of which he crossed the median with the musculo-spiral, in one the median and ulnar with the musculo-spiral, and one in which he joined the central end of the median to the peripheral end of the musculo-spiral, the peripheral end of the former and the central end of the latter being freely excised to prevent reunion. In all the latter three experiments he examined the state of the cerebral cortical centres after return of function.

In the first series of experiments, of which one is published (viz. :—cross union of the median with the musculo-spiral), it was not till the 108th day that the dog was commencing to show return of voluntary extension; by the 202nd day it could support itself on the point of its toes; and at the 271st day it could place the palmar surface of the paw on the ground, give the paw when asked, and hold a bone with the paw against the sound paw, but flexion was so pronounced that it was difficult to judge of the amount of return of extension. At the 311th day the dog was killed, and irritation of the central segment of the median gave no contractions, but of the central segment of the musculo-spiral, flexion. He concludes that the dog is able to carry out with the paw voluntary co-ordinated movements, to hold a bone and give the paw, although the nerves of flexion serve for extension and *vice versâ*.

His second series of three experiments were of the same kind, but had added to them the examination of the condition of the cerebral centres on recovery of function.

In the first experiment the median was crossed with the musculo-spiral, and extension commenced to return on the 30th day. At the 45th day the dog placed the palmar surface of the paw on the ground correctly in walking and running, gave the paw when asked, and used the paw in holding a bone. Later on a flexor contracture developed, and at the 121st day the examination of the cerebral centres showed that the cortical area for the affected fore limb had lost its irritability. He concludes that after crossing, complete voluntary movements are regained, but that there is loss of irritability of the cerebral centres involved.

In his second experiment of this series, in which he crossed the median and ulnar with the musculo-spiral, the examination after complete recovery of function showed that the crossing had failed, that the ulnar had reunited, and that part of the central segment of the median ran into its own peripheral segment, and that the great bulk of the musculo-spiral had reunited. But on cortical stimulation, he found movements of the limb, and this he correlates with failure of the crossing.

In his third experiment he united the central end of the median with the peripheral end of the musculo-spiral, and excised long portions from the unsutured central and peripheral ends. At the 33rd day he found extension commencing in the foot, and at the 47th day the animal supported itself on the sole of the foot in walking and running. At the 102nd day the cerebral cortical centres were stimulated and no irritability could be found. The stimulation of the nerves at the seat of reunion showed that the central end of the musculo-spiral had not reunited, while stimulation of the central median segment gave usually extension, but sometimes flexion, showing that some of its fibres had formed connections with the peripheral median segment.

He concludes from his experiments that the execution of co-ordinated and voluntary movements is possible, although the relationship of the nerves to their centres is altered, and that the altering of the relationship of the nerves to their centres entails the abolition of the irritability of these cerebral centres. In relation to the subject of cerebral localisation of function, he takes the view that the cerebral cortical centres do not represent areas in which, and in which alone, are to be found the only conditions necessary for the innervation of a particular movement, a conclusion which coincides with that expressed by Rawa, who holds that the topography of the cerebral cortical centres is not of necessity fixed, but that it can be altered by external influences.

Howell and Huber (14) also conducted some experiments in crossing the median and ulnar in dogs. Like others who have worked at the subject, Howell and Huber also found the difficulty of getting the nerves crossed to unite without fusing in a common mass, and therefore in their final experiment contented themselves with one crossing, excising widely the remaining two ends. The dogs

operated upon appear to have been very little affected by the division and crossing of their nerves of flexion, for on the second day after the operation, with both median and ulnar cut on the left side high in the limb, and with the ulnar cut on the right side at the level of the elbow, there was very little evidence of any paralysis or even awkwardness. Before the end of the first week the closest scrutiny could detect no awkwardness of movement, except possibly when the animal was running rapidly up-stairs. They allude to the fact that the median and ulnar supply synergic muscles have a close origin, and that a more interesting experiment would be the crossing of the musculo-spiral and ulnar, and think that such would be successful.

CUNNINGHAM (16) conducted two sets of experiments on the fore-limbs of dogs. He invariably made a double crossing, and the precaution taken to prevent confluent reunion of all the nerve ends was to wrap round each union a layer of fascia. In his first set of experiments he crossed the median with the ulnar, and found, as did HOWELL and HUBER, that this operation inconvenienced the animals very little, but in all his dogs there was persistent over-extension. In one of the animals voluntary flexion could be detected. In all of these experiments the cerebral cortical centre for flexion was stimulated, and in all flexion of the paw was the result.

In his second set of experiments he crossed the musculo-spiral nerve with the ulnar and median. This was done in nine dogs, but only four were successful. One of these always came down on the dorsal surface of the paw on attempting to walk, and it was difficult to determine whether it had the power to extend at all, but a subsequent examination by electrical stimuli showed that the nerves had become united and recovered irritability and conductivity. In the other three dogs he found the same progress. Thus one of the animals continually held the forearm flexed, and the paw was not allowed to touch the ground till the 264th day, when the animal attempted to use the foot in walking, always putting down the dorsal surface on the ground. At one year and five months, while the fore-arms scarcely differed in size, there was inco-ordination exhibited. He gives a list of these inco-ordinated movements, of which may be quoted, that when the animal was ordered to give the paw, it lifted up the fore-arm but flexed the paw, and that when it walked the leg was advanced, and at the same time the paw quickly flexed. On cortical stimulation, the results which he obtained were very different from those quoted above from STEFANI, as stimulation of the area for flexion of the paw gave extension, and of that for extension, flexion of the paw.

In a third set of experiments he united the central end of the hypoglossal to the peripheral end of the recurrens, and found that the nucleus of the hypoglossal did not take on the character of a rhythmic discharging centre when united to the recurrens.

He therefore holds that after crossing two motor nerves, the cortical represen-

tation of the groups of muscles supplied by the crossed and united peripheral segment, is "the same as the cortical representation of the groups of muscles that were previously innervated by the central portion before its section," but that this cortical representation differs from that existing before the nerves are crossed in so far that the cortical impulses produce inco-ordinate movements of the muscles supplied by the united crossed nerve; that if the two groups of muscles are synergic the resulting inco-ordination, as in his first set of experiments, is very slight; but that if the crossed nerves are those which supply widely different functions, *e.g.*, antagonists, as in his second set, the adult dog does not regain the power of performing intentional co-ordinated movements; and that there is, as in his third series, abolition of rhythmic action where a non-rhythmic centre is made to connect with the peripheral segment of a nerve, which formerly conveyed impulses from a rhythmic centre.

Important evidence was brought forward by LANGLEY (17, 18) in a series of experiments to determine if efferent cranial "autonomic" nerves could connect with the sympathetic nerve cells of the superior cervical ganglion. He united the central segment of the vagus to the peripheral segment of the cervical sympathetic, taking precautions, which seem to have been effective, to prevent reunion of the divided nerves. From the results of stimulation of the nerves, he concludes that "when the central end of the vagus is joined to the peripheral end of the cervical sympathetic, the vagus is capable of acquiring an influence upon all the structures which are normally influenced by the cervical sympathetic." He assumes that it is not the afferent fibres nor the efferent fibres to striated muscle which make this connection, but the "autonomic" efferent fibres, *e.g.*, motor fibres to the œsophagus, and stomach, and to the lungs, and inhibitory fibres to the heart. But he points out that there being no pilo-motor fibres in the vagus, this function must be assumed by one class changing to another class.

He next discusses the possibility of the acquired functions of the vagus being called into activity by normal stimuli. In proof of the possibility, he obtained in one experiment the effects of stimulation of the cervical sympathetic by stimulation of the centre of the vagus reflexly. Also by noting the rate of diminution or disappearance of the paralytic symptoms after the vagus had been joined to the cervical sympathetic (*e.g.*, contraction of the pupil, dilatation of the vessels of the ear, &c.) he concludes "that the vagus was exercising a greater or less tonic action upon those structures upon which the cervical sympathetic normally exercises a tonic action." He also united the central end of the lingual to the peripheral end of the cervical sympathetic, and noted the recovery of most of the functions of the sympathetic, which he takes to be the result of the connection of the sympathetic formed with the vaso-dilator and secretory fibres present in the lingual from the chorda tympani, and concludes that "the evidence strongly favours the view that the vaso-dilator fibres of the lingual (chorda tympani) after becoming connected with the nerve-cells

of the superior cervical ganglion, become motor fibres for unstriated muscle and in especial vaso-constrictor fibres for the arteries of the ear" (p. 268).

## III. Conclusions from Literature.

There are two vastly different results which may be looked for in experiments on nerve-crossing, viz. :—the return of conductivity through the composite nerve with the possibility of even voluntary, though inco-ordinated, muscular contractions being evoked by impulses passing along the nerve, and in the second place not only the return of conductivity, but the complete re-establishment of voluntary and reflex co-ordinated movements. All who have tested the matter since the publication of Rawa's experiments, have admitted the former possibility, but, as shown above, a division of opinion obtains in respect of the latter possibility. Rawa, Stefani, Howell and Huber, and Langley affirm the possibility, while Schiff. Reichert, and Cunningham deny it.

Two important differences in the details of the experiments which have been published by these authors may account in a measure for the division of opinion. The experiments differ in the nerves chosen for crossing, and in the methods of establishing the crossing. Thus Rawa, Stefani, Howell and Huber, and Cunningham have conducted experiments on nerves of the extremities supplying movements which are under the control of the will, while the experiments of Schiff and Reichert, of Langley, and some of those of Rawa and Cunningham refer to nerves innervating muscles with which the will has little to do. There is a difference, again, between experiments conducted on nerves which innervate voluntary motion, according as the nerves crossed each supply groups of muscles of the same action (synergic) or groups of muscles of opposing action (antergic); for if the crossing cannot be compensated, it is in the latter case that the inco-ordination is likely to be more pronounced. Thus Howell and Huber and Cunningham found little inco-ordination as the result of crossing the median and ulnar, but Cunningham found no return of co-ordination on crossing the musculo-spiral with the ulnar and median. The latter observation is, however, opposed by Rawa and Stefani, who, with the same form of experiment both conclude that return of co-ordination is possible. Schiff's and Reichert's conclusions agree with those of Cunningham, but the experiments of the former were on nerves which innervate for the most part involuntary functions, and, therefore, the non-appearance of alteration of function in the crossed nerve cannot be taken as excluding the possibility of this occurring in nerves which are under the influence of the will, and which, therefore, have this advantage in any process of education in the stage of alteration of function. Schiff now recognises this. To his paper, which is reprinted in his collected memoirs, there appears an addendum in which he criticises the views of Rawa and Stefani. He seems to have performed similar experiments on the nerves of the extremities, and

like STEFANI, to have found restoration of co-ordinated movements. This result he explains as due to the volitional correction by the animal of movements which sensation informs it no longer result from the same impulses as before the experiment. He still, however, maintains the impossibility of an alteration of function after crossing nerves like the vagus and hypoglossal.

This difference between nerves of voluntary and those of involuntary function, however, according to RAWA does not obtain. Thus the latter may have their co-ordinated functions restored through the former, and *vice versâ*, and this view is confirmed by LANGLEY, who finds that stimuli for normal sympathetic functions can be started in the vagus centre and conducted through the vagus nerve.

The mode of carrying out the experiments has also influenced the results. Thus, in order to prevent confluent reunion, RAWA, SCHIFF, and LANGLEY crossed only one peripheral and one central end, widely excising the other two ends. In SCHIFF'S and LANGLEY'S and certain of RAWA'S experiments, this method did not vitiate the results, as the two nerves were distributed to entirely different structures; but in RAWA'S experiments on the nerves of the extremities this method, as stated above, was not compatible with perfect recovery of the limb, as thereby either the flexor or the extensor muscles only were innervated, the opposing group being left unsupplied, a condition necessarily resulting in contracture, which must have made the interpretation of the results extremely dubious. CUNNINGHAM, however, made a double crossing, and prevented confluent reunion by stitching round each seat of union a layer of fascia, while STEFANI made double crossings in all his experiments except one, but except in the latter, seems not to have taken precautions to prevent confluent reunion other than the distance which separated the two points of union. That this was not a safe procedure is shown from the fact that one of his experiments had to be rejected on account of confluent reunion.

STEFANI'S experiments were not followed by a perfect use of the limb by the animal, permanent flexion developing in all in which the crossing had been effective. This is to be explained by the fact that he crossed in them the musculo-spiral with the median only, leaving the ulnar nerve intact. A method of this kind leaves one nerve to supply the flexors as before, while the whole supply of the extensors has to be carried on through the crossed nerve. The balance of opposing action of the two groups is thus disturbed, and the flexors are more than likely in the course of the experiment to exhibit a preponderance of action. The conditions were rightly arranged in CUNNINGHAM'S experiments, in which both median and ulnar were crossed with the musculo-spiral; but he, of course, did not find return of co-ordinated motion.

## IV. The Author's Experiments.

I decided, therefore, to conduct some experiments of the same kind as those of Cunningham, following certain principles which appear to me to be essential in any experiment intended to elucidate the question of restoration of voluntary co-ordinated motion after crossing two nerves supplying voluntary muscles in the limbs. These principles are :—1st. The nerves chosen for crossing must supply groups of muscles with opposing action, *e.g.*, flexion and extension.

2nd. The crossings must involve all the nerves of the limb which conduct efferent impulses, so as to prevent the possibility of a vicarious supply.

3rd. The entire supply of the flexors must be crossed with the entire supply of the extensors to maintain the balance of opposing action and prevent the development of contractures.

4th. There must be some precaution taken to prevent confluent union in a common cicatrix, involving failure of the crossing.

I therefore united the central segments of the median, the ulnar, and the musculo-cutaneous with the peripheral segment of the musculo-spiral, and *vice versâ*, dividing the four nerves on each side of the anconeus internus muscle, the result being that, when crossed and united by suture, the two points of union were separated by the muscle ; this, therefore, forming an effectual barrier against confluent reunion.

*Experiment I.* (Plate 36) *Cross Union of the Central Segments of the divided Musculo-cutaneous, Median, and Ulnar Nerves with the Peripheral Segment of the divided Musculo-spiral, and* vice versâ.—On 15th June, 1898, a collie dog, aged 10 months, was anæsthetised by inhalation of ether after having had a subcutaneous injection of 0·5 gramme morphia sulphate, and the inner side of the right fore-limb, together with the adjacent pectoral region, having been shaved and disinfected, an incision was made from the axilla downwards and backwards to the olecranon. The musculo-cutaneous, median, and ulnar nerves were defined on the inner surface of the anconeus internus muscle, that muscle then drawn inwards and forwards, and the musculo-spiral nerve pulled into the field of operation. The latter nerve was divided well behind the anconeus internus, all its branches to the extensor muscles of the elbow joint coming off from its central segment. The median, ulnar, and musculo-cutaneous having been divided at a level corresponding to that at which division of the musculo-spiral had been effected, the central segments of the former three nerves were united to the peripheral segment of the latter nerve, and *vice versâ*, in both cases by a single suture of chromicised catgut. On completion of the crossing it was seen that the two points of union were well separated by the anconeus internus muscle, and that there was no tension. The fascia and skin were then separately sutured, and a plaster of Paris casing applied from the toes up the limb and round the body.

The wound did not run a perfectly aseptic course, as on removing the splint on the

10th day, there was some pus on the dressings, and the lower two stitches had given way, but no pus exuded from the wound on pressure. The wound was cleansed and the lower part re-sutured, and a new plaster of Paris casing applied, and on removing this on the 19th day the wound was found soundly healed.

The following was the course which was run as far as return of function is concerned :—

From the 1st till the 18th day there was absolutely no recovery of function. Although the limb was supported by the plaster casing, it was not allowed to touch the ground while the animal walked, but was held projecting downwards and backwards. No test could elicit any evidence of return of sensation in the paw.

On the 19th day the plaster was removed, and the animal in walking and running occasionally momentarily placed the palmar surface of the paw on the ground, at once withdrawing it and keeping it held up.

On the 21st day it was found that the dog frequently put its weight in walking on the affected leg, but it always turned over on the dorsal surface of the paw, and, finding no support in this position, the limb suddenly flexed at the radio-carpal articulation, and the animal landed on the end of the radius. This occurred occasionally, but as a rule it kept the leg drawn up while walking or running. To keep the limb in the normal position and prevent the development of contracture, and also to prevent further abrasion of the skin over the lower end of the radius, a plaster of Paris bandage was applied from the toes up to the middle of the radius.

After immobilisation of the radio-carpal joint the animal commenced to use the leg in walking, and was soon doing so constantly; but this of course may have been in large measure, if not entirely, a passive movement.

On the 29th day the plaster was removed, and then the animal, as a rule, walked on the end of the radius with the paw doubled back, this being the result of placing the dorsal surface of its paw down instead of its palmar surface. On a few occasions, however, it placed its palmar surface correctly, but this was so infrequent that it might have been accidental. The carpus was protected from injury by a calico bandage, which also gave the joint some support.

On the 30th day the foot was more frequently placed correctly on the palmar surface, and on the following day still more frequently, and at the 32nd day the animal walked and ran full speed, always placing the paw with the palmar surface down. On this day there was, therefore, a complete return of co-ordinated movements as exhibited in walking and running, but the affected muscles were evidently very weak. The animal, however, did not spare the leg, the result being that in a few days the muscles became so weak that it was unable to support the weight of its body on the limb. A short plaster splint was, therefore, again applied (35th day) to immobilise only the radio-carpal joint, and to keep it extended. With this support the animal used the leg perfectly, always placing the palmar surface down.

On the 90th day the splint, which had been removed and reapplied several times

since the last note, was again removed, and the animal was then using the leg perfectly in walking and running, and continued to do so. It gave the paw correctly on request, the paw being held extended, when the limb was raised.

After this the recovery of power was retarded by a synovitis and slight over-extension commencing in the radio-carpal articulation; but this yielded to treatment by immobilisation of the joint.

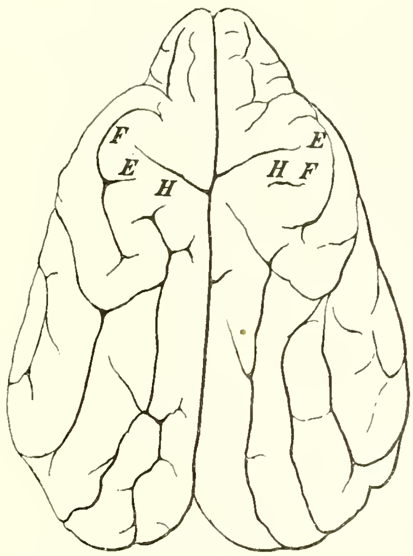
At the 115th day there was distinct evidence of sensation, which might, however, have been present before.

At the 177th day the condition was again examined, and it was found that the muscles of the right fore-limb were greatly increased in bulk, and that the difference in bulk between the two fore-arms was not very marked. The co-ordination of movements of the right limb was perfect in walking, running, and jumping, and in running rapidly up and down stairs, the dog never making a false step. While standing, the animal was observed to make voluntary flexion of the paw, raise the foot from the ground, extend, and again replace the limb correctly. It gave the paw at once on request, the paw being held out fixed in extension. While gnawing a bone it was observed to fix it between the palmar surfaces of the two paws as under normal conditions. There were no trophic disturbances in the skin of the paw, the nails and hair being normal. The only abnormal conditions which could be ascertained were as follows:—When the animal planted its two fore-limbs forward, and rested its whole weight on them—an attitude which is frequently assumed by dogs—the affected limb showed rather more over-extension at the radio-carpal articulation than the sound one. Also as the result of the synovitis from which it had suffered, there was slight swelling at the radio-carpal articulation, and when the paw was flexed it became fixed when it formed an angle of about 80° with the fore-arm. The muscles of the fore-arm were still not so bulky as those of the normal limb.

### *Physiological Examination.*

On 10th December, 1898 (about six months after the operation), the dog having been anæsthetised with chloroform, the roof of the skull was removed so as to expose the portion of the cortex around the crucial sulcus of both hemispheres. The electrodes from a secondary coil with a strength of current only sufficient to be felt on the tip of the tongue, were applied on the sigmoid gyri over the centres indicated by FRITSCH and HITZIG (7). On applying this current on the right hemisphere over the centre for the hind-limb no reaction followed, but on slightly increasing the strength of current the normal reaction, namely, advancement of the left hind-limb was induced. The electrodes were then applied further out on the same sigmoid gyrus, and an area was found here which gave strong flexion of the left fore-paw. Stimulation was then applied at a point still further out and further forwards, this point being situated on the sigmoid gyrus in line with the crucial sulcus, and strong

extension of the left fore-paw was the result. Stimulation of these three points thus gave the reactions described by FRITSCH and HITZIG. The left hemisphere was then examined. The centre for the hind-limb was first determined, and it was found to correspond closely in position with that of the right hemisphere, and to give the same movement of the right hind-limb. The electrodes were then applied to the point on




Cerebral Hemispheres of Dog.

Stimulation at the points marked H produced movements of the hind-limbs; at the points marked E contractions of the extensor muscles of the fore-paws; and at the points marked F contractions of the flexor muscles of the fore-paws.

the sigmoid gyrus, corresponding in position to the centre for flexion on the right hemisphere, and vigorous extension of the right fore-paw was the result. The electrodes were then applied at the point corresponding to the extension centre of the right hemisphere, and here also extension of the right fore-paw was the result. The cortex was stimulated around this at several points, but no flexion movement at this examination could be obtained.

The seat of crossing of the nerves was then exposed, and it was seen that the two points of reunion were widely separated, one lying on the internal face and the other on the external face of the anconeus internus muscle. The central segments of the median, ulnar, and musculo-cutaneous bent outwards to pass to the outer side of the muscle, where their junction with the peripheral segment of the musculo-spiral could be seen. The central segment of the musculo-spiral passed under the central segments of the median, ulnar, and musculo-cutaneous about 2 centims. above their point of union with the peripheral segment of the musculo-spiral. It passed downwards over the internal face of the anconeus internus to make connection with the peripheral segments of the median, ulnar, and musculo-cutaneous about 2·5 centims. lower down.

No communication between the two points of union could be seen. The nerves were then stimulated, each being insulated on a plate of ivory. Stimulation of the central segments of the median, ulnar, and musculo-cutaneous held up together gave vigorous extension of the paw. Held up separately, stimulation of the ulnar gave strong extension at the radio-carpal articulation, and also feeble extension of the digits, while stimulation of the median and musculo-cutaneous gave powerful extension of the digits, and less marked extension at the radio-carpal articulation, the movement being stronger in the case of the median. On the other hand, stimulation of the central segment of the musculo-spiral gave strong flexion of the paw.

The skin and fascia were then removed from the muscles of the fore-arm, in order to see if stimulation of each of the nerves evoked contractions only in the flexors or only in the extensors. Stimulation of the central segment of the musculo-spiral was then seen to give contractions of the flexors and no movement in the extensors, while stimulation of the central segments of the median, ulnar, and musculo-cutaneous gave contractions in the extensors and no movement in the flexors.

The cerebral cortex was again examined to observe the effects of stimulation on the exposed muscles. It had, during the stimulation of the nerves, been protected by the soft parts which had been stitched over it. Stimulated on the centre for flexion on the sigmoid gyrus, the effect was to give on the right hemisphere flexion of the left paw, and on the left hemisphere extension of the right paw, and strong visible contractions in the extensor muscles, without movement in the flexor muscles. Stimulated on the centre for extension on the right hemisphere the result was extension of the left paw, but now on the left hemisphere the flexor muscles of the right fore-arm gave strong contractions. These, however, were usually accompanied by stronger contractions of the extensor group, the result being, as a rule, to give feeble extension of the paw. A point could not be found to give on stimulation contractions of the flexor group unaccompanied by contractions of the extensors. A point which was noted during these examinations was that the excitability of the centres in the left hemisphere seemed to be greater than that of those in the right hemisphere, as the movements caused by stimulation with the same strength of current were more vigorous in the right than in the left limb. The points at which stimulation gave these results were marked at the time that the stimulations were being made, and are shown in the sketch. On completion of the examination the dog was killed, without having been allowed to regain consciousness.

The dissection of the parts after death showed that the nerves had united in the position in which they had been placed at the operation, and without any communication either between the two points of union or by means of any anastomosing branches. In order to establish this point a careful dissection of the whole nervous supply of the limb was made. The musculo-spiral traced from the brachial plexus gave off from its central segment all its branches to the group of muscles which extends the elbow joint. These branches were all traced into their muscles to ascertain that no abnormal

communication was made with the peripheral segment. The central segment then passed to the internal face of the anconeus internus muscle (inner head of triceps), instead of continuing its course round the humerus. In this course it passed under the central segments of the median, ulnar, and musculo-cutaneous, about 2 centims. above their junction to the peripheral segment of the musculo-spiral, to which it was attached merely by loose connective tissue. About $2\frac{1}{2}$ centims. lower down it passed into the apex of a triangular-shaped swelling, the base of which was attached to the peripheral segments of the ulnar, median, and musculo-cutaneous, which followed a normal distribution. At the flexure of the elbow joint, however, the musculo-cutaneous gave off a considerable branch which joined the median.

The central segments of the median, ulnar, and musculo-cutaneous, after following their normal course to the middle of the humerus, turned backwards and outwards to reach the posterior border of the anconeus internus, crossing over in their course the central segment of the musculo-spiral. They passed together over the posterior border of that muscle to reach its external face, on which, about 0·5 centim. from the posterior border, was situated the junction with the peripheral segment of the musculo-spiral, which followed a normal distribution.

EXPERIMENT II.—*Cross Union of the Central Segments of the divided Musculo-cutaneous, Ulnar, and Median Nerves with the Peripheral Segment of the divided Musculo-spiral and* vice versâ.—A collie bitch, aged about 1 year, on 15th February, 1899, was narcotised with 0·5 gramme morphia sulphate followed by inhalation of ether.

The same procedure was carried out on the right fore-limb as in the previous experiment, and the following was the result.

The dog walked about on the splinted leg till the splint was removed at the end of the 14th day. On that day the leg was supported by a plaster of Paris bandage reaching up to the middle of the fore-arm only.

On the 17th day the dog was still holding up the fore-limb when running and walking, except very occasionally, when it placed it on the ground. By the 21st day the leg was much more frequently used, and used alternately with the sound limb in walking.

At the 31st day the dog was using the leg constantly in walking. The plaster support was therefore removed, and it was then found that the dog used the unsupported leg perfectly in walking and running about. Occasionally it bent over, but the dog never allowed the end of the radius to come into contact with the ground when it bent, always lifting the leg and placing it again correctly on the ground. Occasionally it bent over in this way, being immediately readjusted; but on supporting the limb with a simple flannel bandage applied from the claws up nearly to the elbow, the dog ran about, never, as far as could be observed, making a false move with the limb.

On the 34th day improvement had continued, and now the dog gave the paw on request.

The improvement continued, although there was evidence of weakness of the leg, *e.g.*, slight over-extension at the radio-carpal joint. This was remedied by putting the limb in a plaster splint for a week.

On the 105th day the dog still used the leg well. Given a bone it used the affected leg to hold it while gnawing, but not so well, of course, as the sound leg; but sufficiently well, nevertheless, to show that there was recovery both of power and of co-ordination of movements.

The animal was then submitted to a physiological examination, having been anæsthetised with ether. The brain having been exposed, faradic stimulation of the left sigmoid gyrus gave the following results. Stimulation of the centre for the hind-limb gave the normal contraction of the hind-limb. Stimulation further out in the position of the normal flexion centre for the fore-limb gave distinct extension of the paw, while stimulation still further out and further forwards in the position of the normal extension centre gave very marked flexion of the paw and no trace of extension movements.

The nerves at the seat of crossing were then exposed. Stimulation of the central segment of the musculo-spiral gave strong flexion, which was visible in the exposed flexor muscles, and absolutely no contraction in any of the extensor muscles which were laid bare for inspection. Stimulation of the central segments of the three flexor nerves gave pure extension, and no movements whatever in the exposed flexor muscles. The three nerves stimulated separately gave equal results, *i.e.*, extension at wrist and of digits.

After the irritability and conductivity of the nerves had been investigated by direct stimulation of the central segments, the brain was again stimulated in order to ascertain the effects of stimulating the cerebral centres as evidenced by contractions in the exposed muscles of the fore-arm. The brain had been carefully protected during the experiment by stitching the soft parts over it. The result of stimulating the normal flexion centre was that contractions were visible in the extensor muscles, while the flexor muscles, carefully watched, showed no contractions whatever. Also, on stimulating the normal extension centre on the left side, the extensor muscles showed no contractions, while the flexors were thrown into vigorous contractions.

Stimulation of the right gyrus gave the normal reactions in the left limb.

The muscles of the right fore-arm were healthy, though somewhat less bulky than those of the other leg.

The dissection of the limb showed that the crossing was efficient, there being no communication between the two sets of nerves crossed.

EXPERIMENT III.—*Section and Accurate Reunion by Suture of the Musculo-cutaneous, Median, Ulnar, and Musculo-spiral Nerves.*—On 25th March, 1899, a collie bitch, aged $1\frac{1}{2}$ years, was narcotised by a subcutaneous injection of morphia sulphate, 0·5 gramme, followed by inhalation of ether. The right fore-limb was again chosen for the experiment, and the same antiseptic precautions having been taken as in the

other experiments, the same exposure of nerves was made. The musculo-spiral was brought up from between the muscles and a suture of chromicised catgut placed through the nerve before its division, in order to ensure accurate reunion after division. The suture having been placed, the nerve was divided and the ends brought together again by tying the suture. The median, ulnar, and musculo-cutaneous nerves were then similarly exposed and a suture of chromicised catgut placed through each, the nerves divided, and accurately reunited by tying the sutures.

Thus all the nerves supplying muscles below the elbow joint were divided and at once reunited as accurately as possible. The wound was then closed with silkworm gut sutures, and the entire limb immobilised as in the previous experiments.

On the 13th day the plaster splint was removed and the wound was found absolutely healed, and the stitches were removed.

By the 17th day the dog had not been using the limb in walking, and a distinct flexor contracture was commencing to form. A short plaster splint was applied to immobilise only the radio-carpal joint, and thus to prevent this contracture.

On the 25th day the plaster splint was removed, as the dog was usually using the splinted leg in walking. On liberating the dog it ran about, occasionally using the leg.

By the 32nd day the short splint had to be again applied, as the dog had not been using the leg, and a contracture was again beginning to develop.

On the 43rd day the plaster support was again removed, and a flannel bandage applied, which enabled the animal to run about, using its leg fairly well.

By the 50th day the animal was, as a rule, using the leg in walking, but the muscles were still very weak, as not infrequently the leg doubled under it, and the animal landed on its radio-carpal joint.

The plaster splint had to be applied on two subsequent occasions, as the tendency to flexor contracture began to show.

On the 94th day the plaster was removed, and the dog then used its limb in walking, standing, and running, but on the following day the tendency was again not to use the limb.

On 28th June, 1899, the physiological examination was made, the animal being under the influence of chloroform and ether. The brain was exposed, and the sigmoid gyri stimulated. The centres for the hind-limbs were well defined, but the centres for flexion and extension of the fore-limbs were not well defined, but the tendency was to get flexion nearer the middle line and extension by applying the electrodes further out. The condition was exactly the same on the two hemispheres. The seat of section was exposed, and stimulation of the central ends of the musculo-cutaneous, median, and ulnar nerves gave strong contractions in the flexor muscles, and stimulation of the peripheral segments of the same nerves gave contractions in the same muscles, but less strong. Stimulation of the central end of the musculo-spiral gave strong contractions in the extensor muscles of the paw, and stimulation of the

peripheral segment of the same nerve gave somewhat weaker contractions in the same muscles.

## V. Comparison of Experiments.

In the first two experiments the same procedure was carried out, the one experiment simply being a repetition of the other. In the third experiment the same nerves were divided, but each nerve was simply reunited as accurately as possible, with the object of ascertaining if the fact of crossing appreciably affected the recovery in any way. The third experiment had the advantage of the wound healing by first intention, while in the two in which the crossing was carried out, the wounds did not heal absolutely by first intention.

*a. Restoration of Voluntary Co-ordinated Movements.*—In the animals in which the nerves had been crossed, both may be said to have regained completely or almost completely voluntary co-ordinated movements of the limb. Their recovery of the use of the fore-limb was at least so good, that no doubt could be entertained of the return of voluntary co-ordinated movements. Thus the animals made constant and correct use of the leg in running and walking, placing the paw on the ground correctly, palmar surface down, and without exhibiting over-extension at the radio-carpal joint. (Plate 36.) They could stand on the affected limb while they gave the opposite paw. (Plate 36, fig. 2.) They also on request gave the paw of the affected leg in a perfectly normal manner, showing good extension power at the wrist joint in so doing. In gnawing a bone the sound paw and the affected paw were used together to hold the bone in a fairly normal manner.

Thus very good recovery of function was obtained, but not without very considerable trouble, and not without the lapse of a considerable time. As regards the first indications of recovery of function, these were shown in both about the same time. About the 30th day the dogs commenced to use the leg in walking or running, without the support of a splint, and gave the paw on request. In neither case did this recovery of function progress steadily from the time of its first exhibition. The constant early use of a limb, whose muscles were in a very weakened condition, gave rise to a state of over-extension at the radio-carpal joint. For this over-extension the remedy employed was to fix for a few days the limb, in the normal position for standing, in a plaster of Paris bandage, only the radio-carpal, the joint affected, being thus immobilised. By means of this treatment the tendency was combated, and the ultimate complete recovery of function attained. Almost complete recovery dated from the 45th to the 90th day after the operation.

In the case of the third experiment it was found that the fact of the divided nerves being united in their old position without any crossing, did not result in a recovery of function any sooner than in the experiments where nerve-crossing had been done. Thus the earliest signs of recovery of function were exhibited on the 25th day, but at this date the animal was only occasionally using the leg, and in a

few days, just as in the other experiments, it ceased using the leg and held it up while running and walking. Even after the 90th day, a tendency was exhibited to flexor contracture, but the object of the experiment having been attained, the animal was not allowed to live longer. Thus in the case of the third experiment, the course of restoration was not markedly different from that of the cases in which the same nerves were divided and united in a crossing.

The nerves which were divided and crossed, involved the entire supply of the muscles below the elbow joint, and of these nerves the entire supply of the flexors was crossed with the entire supply of the extensors. There was no excising of any part of the nerve, all the fibres were made to take part in the crossing. Thus, impulses descending the musculo-cutaneous, ulnar, and median nerves were diverted from the flexor muscles, their normal destination, and instead directed down the peripheral segment of the musculo-spiral, being thus made to supply the extensors. On the other hand, the impulses for the extensor muscles descending the musculo-spiral were diverted at the crossing and descended the peripheral segments of the musculo-cutaneous, median, and ulnar, thus supplying the flexors instead of the extensors. Thus the entire nerve supply of the flexors was crossed with the entire nerve supply of the extensors. It was in order to ensure this that the musculo-cutaneous was included in the crossing, and the precaution turned out to have been necessary, as, when the animals were dissected, it was found that, in all, the musculo-cutaneous gave off at the elbow a large branch which joined the median nerve. This large communicating branch might have contained efferent nerve fibres which contributed to the supply of the flexors, and in Experiment III. the physiological examination proved this to be the case.

On comparing these results with the results published by others, it is found that the only somewhat similar experiments published, with which a comparison can be instituted, are those of STEFANI (13) and of CUNNINGHAM (16). In RAWA's (10) experiments, the nerves divided were the posterior tibial and peroneal, and as one crossing only was made between the two nerves, the other two ends being widely excised, he had, therefore, as already mentioned, no case of nearly perfect restoration of function. From this cause, and from the fact of the experiments having been conducted on the hind-limb, a fair comparison cannot be made.

In the case of STEFANI's experiments, the crossing was not exactly the same as in the experiments here recorded, not involving the entire supply to the muscles below the elbow. Thus, of the four experiments of which he gives details, three consisted of crossing the median alone with the musculo-spiral. His remaining experiment, which consisted in a crossing of the median and ulnar with the musculo-spiral, and which was therefore more complete, was unfortunately vitiated, as the crossing did not turn out to be efficient. In two of his experiments, in one of which, however, the crossing was not absolutely efficient, the restoration of function followed a course which was very closely the same as in the experiments here recorded. Thus the first

indications of restoration were exhibited about the 30th day and were greatly improved by the 45th to the 47th day, but in the further course the restoration was interfered with by the development of over-extension in the one case and flexor contracture in the other. This prevented the animals making a complete recovery, as proper means do not seem to have been taken to prevent the development of these conditions. In my experiments, when the same conditions were shown, the limb was immediately supported by a plaster of Paris splint, the effect being that the muscles obtained the necessary rest for a few days.

In CUNNINGHAM's experiments, in which the ulnar and median nerves were cross-united with the musculo-spiral, there was no restoration of voluntary co-ordinated movements, although the nerves had united in an efficient crossing, as was proved by electrical stimulation.

In none of these cases was the crossing of the supply of the flexors with that of the extensors complete, as the musculo-cutaneous may have given off a communicating muscular branch to the median and thus continued to supply the flexors. In all STEFANI's effective experiments the ulnar nerve was left to continue the supply of the flexors as before.

Important factors in obtaining return of function are prevention of suppuration in the wound, immobilisation of the entire limb during healing, and maintenance of the limb in the extended position until voluntary function returns. If the last-named precaution is not observed, the position of flexion which the limb assumes while still paralysed is apt to pass over into a condition of contracture which will hinder functional restitution.

*b. Efficiency of the Crossing.*—To ensure efficiency of the crossing is a point of great importance. If the nerves are simply divided and cross-sutured in close proximity, the result will be that all the ends will unite in a common cicatrix. In my experiments the points of cross-union lay on opposite sides of a bulky muscle—the anconeus internus or inner head of the triceps—through which communication was impossible. When possible to carry out, this method is a very efficient one. The precaution employed by CUNNINGHAM of rolling fascia round the seats of cross-union seems to me to be liable to failure, as presenting a barrier which might be penetrated by developing nerve fibres. Also, the method of RAWA and others of making one cross only and widely excising the two remaining ends is suitable only in crossing nerves which do not supply muscles of opposing action.

*c. Position and Irritability of the Cerebral Cortical Nerve Centres.*—In all the experiments the surface of the brain was exposed at the physiological examination, and the condition of the cortical centres examined by means of stimulation with a weak interrupted current. In all cases both sigmoid gyri were examined, in order to contrast the normal with the abnormal side. In each instance, also, the brain was exposed and stimulated before the nerves were exposed, in order to observe the movements of the limb before the muscles were disturbed In order, however, to make

certain whether the stimulation of a particular centre evoked contractions only in the extensors or only in the flexors, these muscles were exposed after the examination of the seat of crossing had been made, and the surface of the brain again stimulated. It was possible, although the movement of the paw produced by stimulation of a centre was flexion or extension, that the stimulation might at the same time cause some contractions in the opposing set of muscles, contractions too weak to resist the opposite movement.

As the result of these examinations it was found that in Experiment I. the centres controlling flexion and extension of the fore-limb which had been operated on, had interchanged their positions. The extension centre was quite distinct and pure, and situated in the position occupied normally by the flexion centre, while further out and further forwards in the normal position of the extension centre was situated the only point, stimulation of which caused contraction of the flexor muscles of the paw. This centre was not, however, pure, as contractions of the flexors were almost always accompanied by stronger contractions in the extensor muscles. Compared with this condition, the opposite side of the brain showed the centres of the fore-limb to be well defined and situated normally.

In Experiment II. the result of the examination was even more distinct; for in this case the affected gyrus showed the centres for flexion and extension perfectly well defined and pure, but with their positions interchanged. The opposite gyrus also showed the two centres situated normally and well defined.

In Experiment III., in which the nerves were not crossed, cerebral stimulation showed the flexion and extension centres situated in their normal positions, being similarly situated on the two opposite gyri; but in this case neither on the one nor on the other side were the two centres very well defined, as there was always a certain amount of contraction in the flexors when the extension centre was stimulated, and *vice versâ*.

As regards the degree of irritability of the two sides of the brain in the experiments in which the nerves had been crossed, there was no diminution of irritability of the affected side exhibited, but rather the reverse. Thus, contractions of the muscles of the affected limb in both cases were evoked by an interrupted current too weak to produce contractions when applied to the normal side, and currents sufficiently strong to call forth movements when applied to the normal side were able to produce a more vigorous movement on the affected side.

The condition of the cerebral centres shown in these experiments agrees with that which was found by CUNNINGHAM in his experiments, but is different from that which STEFANI describes; as the only case in which STEFANI found irritability of the affected side of the brain was a case in which the crossing had not remained efficient, and in which, therefore, the muscles continued presumably to receive supply from their old sources, and in all his cases in which the crossing remained efficient, the irritability of the cerebral centres disappeared.

## VI. Deductions from the Experiments.

From the results which have been recorded, it seems to be evident that in the case of two groups of opposing muscles, the nerve supply of the two groups may be interchanged, with the result that, after the lapse of a time sufficient for the regeneration of the divided nerves and repair of the degenerated muscles resulting from the temporary loss of nerve supply, the functions of the two groups of muscles are restored. This restoration of function is very complete; for not only does it mean that contraction can be voluntarily produced in the group of muscles, but that voluntary co-ordinated contractions can be produced in the two groups so as to produce movements of the part in perfectly normal co-ordination. The fore-limb of the dog is particularly well suited for testing this question, as it is only possible for the animal to use the limb in walking if the muscles are efficient. In the case of the hind-limb the animal may continue to use it in walking even although the nerve is divided and not reunited, the only abnormality being that the paw frequently turns back, and the animal treads on the dorsal surface of the paw. This possibility is brought about by the ligaments of the hind-limb, giving the limb a rigidity sufficient for support in walking. In the case, however, of the fore-limb, if the paw is not laid down on the ground with the palmar surface down, if by any chance it is doubled in and laid with the dorsal surface down, then the animal finds no support on the limb, and lands on the end of the radius. It is only when the animal has so far recovered as to be able to put the palmar surface down, that it has sufficiently recovered to be able to use the limb. Using the affected fore-limb in walking means, therefore, a recovery of a certain amount of co-ordinated movement.

The fore-limb is also used for a number of other co-ordinated movements, such as giving the paw on request, fixing a bone while it is being gnawed, &c., and these enable the progress of recovery to be easily recognised.

The alterations which are brought about by interchange of innervation can, therefore, be compensated, and this, again, throws light on the question of restoration of function after reunion of a divided nerve. It is thus not necessary at all that the old paths for the nervous impulses should be restored. In the process of regeneration of the nerve, muscular fibres may become innervated by new nerve cells, muscles and groups of muscles by new nerve centres, and yet, so far as concerns the capacity for making co-ordinated movements, this alteration is able to be completely compensated.

The experiments have an important bearing on the question of interchange of function of the cerebral centres. They show that in the dog, at least in the case of volitional centres, interchange of function as regards co-ordination may be brought about by altered circumstances, and that this interchange of function may be so perfect that with such centres brought into connection with muscles with which formerly

they did not connect, not only, as CUNNINGHAM believes, may voluntary movements in the muscles be possible, but voluntary movements may be carried out in as perfect co-ordination as under the old conditions. Thus the alteration extends to the cerebral cortical centres, and is not, as STEFANI believes, limited to lower centres with destruction of the cortical centres. This is proved by the results of cerebral stimulation, which have already been described; for the centre for flexion in Experiments I. and II. was clearly interchanged in position with the centre for extension.

The return of voluntary co-ordinated movements, involving the interchange in function of the cortical centres for flexion and extension, might be explained as the result of a process of education, the source from which the brain derives its information of the new conditions, and of the necessity for an alteration of movements, being, as SCHIFF points out, the afferent impulses. SCHIFF takes these afferent impulses to be those which ascend from the radio-carpal joint and skin of the fore-arm, which are supplied by nerves which have not been included in the crossing, and he disregards the muscular sense. But the afferent impulses which are of educational value are probably conveyed along the crossed nerves after functional union has been effected. It is difficult to estimate in dogs the exact date of recovery of sensation, as the animals will only indicate restoration of sensation when recovery is advanced sufficiently far that pain can be produced by stimuli applied to the skin. Thus, for a considerable time after restoration of sensation, the animals will, unless of irritable temper, allow needles to be thrust into the limb without making any sign, for the simple reason that such, although producing sensation, do not produce pain. It may, however, be taken from analogy with the condition in man that sensation is restored earlier than motion; for with the restoration of conductivity of the nerve, sensation returns. In the case of motion, however, the muscles rapidly undergo some degeneration as the result of the temporary deprivation of the influence of the nervous system, and only begin to recover on restoration of conductivity of the nerve, and after this event some time must elapse before they are capable of responding to normal stimuli.

On recovery of the muscles the earlier restored sensation might lead to a voluntary alteration of the function of the centres in the following way :—When the animal allows the paw to touch the ground for the first time after restoration, contact on the palmar surface is felt as contact on the dorsum. The animal thus feels that the dorsal surface is directed downwards, and to correct this tries to make the movement which before the crossing produced extension. This effort at movement, however, now produces flexion, and the result is that placing its weight on the ground with the dorsal surface of the paw directed downwards, and finding no support in this position, it falls on the lower end of the radius. It therefore is informed that something is wrong, and learns by repeated experiences that, in order to attain a rigid position of the foot with the palmar surface down, the opposite movement of what was formerly flexion has to be made. When this is established, then what was formerly dorsal

sensation will be recognised as palmar sensation and *vice versâ*, and localisation of sensation will be regained, and with it co-ordination of movements.

Whether or not the above is the exact process by which compensation is brought about, yet there is little doubt that the afferent impulses play a very important *rôle* in the elaboration of co-ordinated movements. It is in accordance with them that the discharges from the motor centres, which call forth co-ordinated movements, are made. This view receives support from the well-known results of cutting the posterior spinal roots supplying a limb; for under such circumstances, although the anterior roots are left intact, the animal loses all power of performing volitional co-ordinated movements, while inco-ordinated movements may be observed. This applies to the case in question. All the nerves of the paw were cut, and on restoration, the afferent fibres regaining function at the same time as the efferent, the brain is informed through the former of the results of its impulses transmitted through the latter.

## VII. Junction of the Peripheral Segment of the Divided Facial Nerve with the Trunk of the Spinal Accessory Nerve for the Treatment of Facial Spasm in a Woman (Plate 37).

The following case of facial spasm came under my observation while engaged with the above experiments. The case was referred to me by Dr. Thomas Reid, who saw the patient at the Glasgow Eye Infirmary. Being convinced that voluntary co-ordinated movements had been restored after nerve-crossing in the dog, I decided to treat the case by dividing the facial nerve and grafting its peripheral segment on to the spinal accessory nerve, in the hope that the same result of nerve-crossing would result in man as had been proved to take place in the dog.

A similar operation was first proposed early in 1898 by Faure (19) and Furet, and by the former put in practice in the case of a patient who suffered from facial paralysis. Their operation consisted in attaching the peripheral segment of the facial nerve to the central segment of the branch to the trapezius of the spinal accessory nerve. Faure published his case nine months after the operation, and at that date no recovery of function had taken place. A success in this case was hardly to have been expected, as the facial nerve had been divided eighteen months before the operation was undertaken, and the facial muscles were probably, therefore, degenerated beyond the possibility of recovery.

The history of my case is as follows :—

Mrs. I., aged 46, was admitted to the Glasgow Western Infirmary* on 1st May, 1899, on account of incessant muscular twitchings on the right side of her face of ten years' duration.

* I have to express my indebtedness to Dr. Alexander Patterson, who very kindly gave me accommodation for this case in his wards.

*Present Condition.*—The patient appears to be healthy. On the right side of the face there is constant twitching, and the right angle of the mouth is almost constantly pulled up in a tonic spasm. The clonic contractions most evidently involve the zygomatici and levator labii superioris, while the finger inserted into the mouth recognises a hard contracted buccinator. The only thing which momentarily arrests the twitching is when the patient opens her mouth to the full extent. The orbicularis palpebrarum also contracts synchronously with the other muscles, giving the appearance of winking.

When she is resting, she frequently has a peculiar sensation just below the lobe of the right ear.

The eye, nasal fossæ, throat, and ear were examined, without showing anything likely to be of importance in the condition. The vocal cords were passive while the twitching was proceeding in the face.

The patient's past history revealed nothing considered to be of importance in the case.

*Operation.*—On 4th May, 1899, the facial nerve was divided close to its exit from the stylo-mastoid foramen. The peripheral end of the nerve was then drawn downwards to meet the trunk of the spinal accessory nerve at the lower border of the digastric muscle. At this point the trunk of the spinal accessory was divided, but one side of the perineurium was left intact so as to maintain the two divided ends in proximity. Into this gap the peripheral end of the facial nerve was fixed by a suture.

On recovery from anæsthesia the face was inspected, and was found, of course, to be in complete right-sided paralysis. Asked to close her eyes, the right eye remained completely open, and the eyeball rolled up. The angle of the mouth drooped, and, asked to open her mouth, the lower lip opened incompletely on the right side. The brow on the right side was smooth and could not be wrinkled, the buccinator was flaccid, and the naso-labial sulcus was badly marked.

On the 7th day the paralytic condition of the face remained in the same condition as it was immediately after the operation, except that there was a very slight movement of the upper eyelid possible, but it could not effect closure of the palpebral fissure more than about a quarter.

On the 18th day the condition of facial paralysis still continued. Only very slight movements of the upper eyelid were possible, but it was still impossible for her to close the right eye voluntarily. The brow could not be wrinkled on the right side. When she was eating, she was very much troubled with food accumulating between her cheek and gums. She was quite unable to pronounce correctly the labial letters. The picture of unilateral paralysis was still complete, except as regards the slight movement of the upper eyelid.

An electrical examination of the condition showed that the faradic irritability of the entire musculature of the right side of the face was lost, except for some doubtful

contractions in the orbicularis palpebrarum. The faradic irritability of the right sterno-mastoid and upper portion of the right trapezius at its insertion was also lost. The galvanic current, however, gave good though sluggish contractions in the muscles of the face, in the sterno-mastoid, and affected portion of the trapezius.

On the 49th day it was found that the eye could be closed rather better than when the patient was last seen. The palpebral fissure could be closed to about one-half of its extent, and almost completely when the patient was in the horizontal position. The eyeball itself showed no sign of ulceration or inflammation, and the patient found that she now was much less troubled with dust getting into the eye. There was, however, no sign of any further improvement in the movements, except in the case of the eyelid.

The galvanic current continued to give good contractions when directly applied to the muscles, but now, when applied over the peripheral segment of the facial nerve, the facial muscles were thrown into contractions. The faradic current now gave a distinct contraction in the orbicularis palpebrarum when the electrode was applied to the muscle directly, but in the other facial muscles no response was got by the interrupted current. The upper and outer portion of the trapezius and the sterno-mastoid were now giving slight contractions with the faradic current.

By the 123rd day there was still further improvement to record, for now the appearance of unilateral facial paralysis when the face was in repose was much less, although, on movements of the face being made, the paralysed condition was still quite evident. The orbicularis palpebrarum remained much as at the 49th day. An improvement, however, consisted in the fact that she was no longer troubled with food lodging between the gums and cheek. When she lay down she could close the eye fully.

By the 141st day the faradic irritability had improved, as now not only did the orbicularis palpebrarum respond, but the angle of the mouth was drawn up on applying the electrode.

At the 155th day the faradic irritability was very markedly improved, as now sharp contractions were obtained when the electrode was applied to the lower lip, upper lip, cheek, orbicularis palpebrarum, and brow. Also, on applying the electrode to a point of the skin situated over the junction between spinal accessory and facial, the face was thrown into contractions. The faradic irritability of the sterno-mastoid and affected part of the trapezius was now strongly developed.

On the 172nd day there were some indications of power to make voluntary movements of the face in addition to those of the eyelids.

On the 176th day the secretion of saliva was watched, and it was found that on stimulation by means of a weak acid solution applied to the mouth, the secretion was emitted equally copiously from the ducts of the two sides in the case of the parotid and submaxillary glands, and in a continuous stream. This observation was made with the object of determining if any spasmodic emission was made from the submaxillary duct.

By the 190th day the voluntary movements were more distinct, and the angle of the mouth could now be slightly moved. The naso-labial sulcus was now as well marked as on the opposite side.

At the 254th day the faradic irritability was again ascertained, and it was found that it was as well marked as on the opposite side of the face. It was noted that on throwing the side of the face into contractions by applying the electrode over the nerve, the motor point of the nerve on the left side lay immediately below the lobe of the ear, but on the right side, nearly 2 centims. lower down, at a point corresponding to the point of junction between the facial and spinal accessory. Till now the patient had been having electrical treatment twice or thrice weekly, but this was now stopped.

On 17th August, 1900 (470th day) the condition was as follows: She experiences no difficulty on account of the condition of the face. There has never been any return of the spasmodic condition. The conjunctiva of the right eye is quite normal, and she never is troubled with dust getting into it, as winking is perfectly efficient, the lachrymal secretion is not in excess, and she can shut the eye completely, although not so tightly as in the case of the sound eye (Plate 37, fig. 5). The right side of the brow can be wrinkled to a very slight degree only, and movements can be made in the cheek and mouth, but they cannot be well co-ordinated. Thus she cannot make a definite contortion of the face—*e.g.*, in blowing, the aperture of the mouth cannot be made circular. The labial letters are, however, perfectly pronounced, and the buccinator is efficient to prevent accumulation of food between cheek and gums during eating.

There is no atrophy of the side of the face, and in repose there is no appearance of facial paralysis, the muscles having regained their tonus. In Plate 37, fig. 4, the face was intended to be in repose, but the effort which she made to keep the eyes open during the magnesium flash by which the photograph was taken has betrayed the weakness of the right frontalis.

As regards the trapezius and sterno-mastoid, recovery is perfect.

As regards the electrical reactions, nothing further is to be noted, except that stimulation of the facial on the left side causes no movements in any of the facial muscles of the right side of the face, and *vice versâ*, and also that stimulation of the point of junction between spinal accessory and facial causes not only contractions of the muscles of the face, but also of the sterno-mastoid and trapezius.

At this examination it was noticed for the first time that when movements are suddenly made of the upper part of the trapezius, there are violent contractions at the same time involuntarily caused in the muscles of the face. Thus, when the patient suddenly raises her right arm, the face at the same time is thrown into contraction—*e.g.*, the brow is wrinkled, the angle of the mouth drawn up, and the eye half closed, but the eye seems least affected, being evidently much better under control (Plate 37, fig. 6). These contractions are, however, only evoked at the moment of raising the arm, and speedily pass off, although the arm is kept held up

## VIII. Deductions from the Case.

From the report of the case it is evident that the peripheral segment of the facial nerve had made an efficient union with the spinal accessory nerve. There is also no doubt that the recovery of function was due to impulses transmitted along the spinal accessory, and not to a reunion of the peripheral with the central segment of the facial nerve. This latter possibility was rendered extremely unlikely by the fact that the facial nerve was cut close to its exit from the stylo-mastoid foramen, and that, between the cut central end and the point of attachment of the peripheral end of the facial to the spinal accessory, there lay the posterior belly of the digastric. In the experiments on dogs the anconeus muscle formed an efficient barrier against the possibility of confluent reunion, and the same no doubt was fulfilled by the digastric. That the facial nerve was now a branch of the spinal accessory was rendered certain when it was discovered that on raising the right arm suddenly, the muscles of the side of the face were thrown into contractions. This could not have been, if the spinal accessory impulses did not reach the face. That no reunion had taken place between the two ends of the facial, was shown by the absence of all contractions in the facial muscles on stimulating over the normal motor point for the facial nerve, which on the sound side was situated close under the ear. On the affected side the motor point was situated nearly 2 centims. lower, and, therefore, just over the point where the junction between the two nerves had been made.

The facial nerve was grafted on to the spinal accessory, the sheath of the latter nerve not being completely divided, and, therefore, there was no deficiency left in the distribution of the spinal accessory. There was of course a temporary paralysis of the sterno-mastoid and trapezius, due to the section of the nerve, but these muscles continued to get their supply from the spinal accessory after regeneration of the nerve. It remains to be seen by trial in future cases if it would be better to dissociate the movements of the face from those of the trapezius and sterno-mastoid by devoting the entire trapezius branch of the nerve to the supply of the face as in Faure's operation, sacrificing part of the trapezius.

As already indicated, the electrical reactions, both of the facial muscles and of the facial nerve, together with the sudden contractions produced in the face on raising the arm, proved not only that union had taken place between facial and spinal accessory nerve, but also that this union was efficient to allow nervous impulses to be transmitted to the muscles of the face.

There is, however, another point to inquire into, namely, whether these nervous impulses could at will or under the influence of reflexes be transmitted along the new connection in such a way as to call forth in the muscles co-ordinated movements, as was proved to be the case in the experiments on dogs; if, in other words,

the spinal accessory was able to take the place of the facial nerve in an adequate manner. That this was the case, the following observations may be taken in evidence.

1st. *Shutting Eye—Winking.*—That the function of the orbicularis palpebrarum had been restored to a perfectly adequate degree, the condition of the conjunctiva proved; for there was no evidence of inflammation or of ulcerative process, nor increased secretion, nor overflowing of tears. The conjunctiva was perfectly normal. The orbicularis palpebrarum therefore fulfilled this function perfectly, and thus was acting when stimulated reflexly. Also, when asked to shut her eye, she could do so completely, showing that voluntary control was also restored. (Plate 37, fig. 5.)

2nd. *Tone of Facial Muscles.*—At first the tone of the facial muscles was lost, and the typical appearance of profound unilateral facial paralysis was produced, but this appearance gradually wore off until the face presented in repose no sign of paralysis at all, but on the contrary the natural sulci and prominences were as well marked as on the opposite side. (Plate 37, fig. 4.)

3rd. *Efficiency of Buccinator.*—Great improvement was manifested in the condition of the buccinator. In the early stage of the recovery, it was quite inefficient to prevent accumulation of food between the cheek and gums while eating, but ultimately had so much recovered that this disagreeable occurrence was never at all experienced.

4th. *Movements of Lips.*—The power to form a circular opening while whistling or blowing was not, when the patient was last seen, completely regained. Some improvement was observed, but not by any means a complete recovery. Evident improvement in the movements of the lips had, however, taken place, as shown by the recovery of ability to pronounce correctly the labial letters. At first, and for long, it had been almost impossible to do so, but the recovery in this respect had been perfect.

5th. *Other Movements.*—She has the power slightly to contract the frontalis of the affected side, although there is still room for much improvement. She can also make movements of the affected side of the mouth, although they are far from being under control.

The orbicularis palpebrarum was the earliest to show improvement. It preceded any other improvement by a considerable period, and the movement which it produces is the only one which, as far as the observations went, is almost perfected. This precedence of the orbicularis palpebrarum over the other muscles is not surprising, as it is this muscle which of all the muscles of the face is most frequently called into use, and indeed is not only voluntarily called into action, but constantly while the patient is awake, by reflex stimuli. The afferent paths of this reflex being still intact, an effort of will would very early and very constantly be called in to hasten the recovery of the muscle.

The question may arise if the recovery of the face might be due to nervous anastomosis, or to vicarious movements. It might be possible that the nerve of the

opposite side would anastomose across the middle line, and supply some of the fibres of the opposite orbicularis palpebrarum and other muscles. If this were so, then stimulation of the sound facial nerve with the faradic current would cause contractions, not only on its own side of the face but also on the affected side. This was examined on several occasions, but no contractions could be produced on the opposite side by stimulating the sound facial, either with the galvanic or with the faradic current.

Production of movements vicariously necessarily require that although certain muscles in a part are paralysed, there are others remaining sound in the neighbourhood which can imitate the function of the lost muscles. Such can occur in partial paralyses of the limbs, and cases of the kind have been published by LÉTIÉVANT (21), BÄUMLER (22), THOMAYER (23), and myself (24). In the case of the face, however, the entire musculature of the one side was paralysed by the section of the facial, and, therefore, recovery of function could not be explained as substituted function.

From these observations there remains no doubt that the spinal accessory nerve, in the case recorded, was supplying the function of the facial nerve very well, and this was at fifteen months after the operation. Now, in cases of reunion of a nerve, such as the median or ulnar, the recovery of the muscles is often by no means perfect so early as fifteen months after the operation; the cases undergoing much improvement gradually for a considerable time subsequently. Yet the median and ulnar nerves have not more intricate movements to call forth than the facial nerve. It is, therefore, reasonable to suppose that the improvement in the case recorded has not so far reached its termination, but rather that it will continue to progress for some time to come.* At present, however, the recovery is ample to justify the deduction that the spinal accessory is supplying adequately many of the functions of the facial nerve, and to justify the repetition of the operation, either in cases of spasmodic affection, or in the case of paralysis of the nerve from destruction of the portion situated in the aqueduct of FALLOPIUS due to caries originating in inflammation of the tympanum. In cases of the latter kind, however, the choice of the time for operating will be a difficulty, and on it will largely depend the chances of success. If undertaken too early, then it might be an unnecessary interference, as many of the paralytic cases spontaneously recover. If, on the other hand, spontaneous recovery were waited on too long, then the degeneration of the muscles of the face, inevitable when their nerve supply is cut off, might have passed beyond the limit up to which recovery is possible. In the case of spasmodic affections, however, the date of operation is of little importance, as the nutrition of the muscles remains perfect, although they are kept by the affection in a state of constant or of intermittent contraction.

* Since the above was written with reference to the condition at fifteen months after the operation, the patient has continued to improve, and now (30th March, 1901), nearly twenty-three months after the operation, she has acquired still more control over the facial muscles, and there has been no return of the facial spasm.—R. K.

## IX. General Conclusions.

1. In the fore-limb of the dog the nerve supply of the flexor muscles may be crossed with that of the extensor muscles, with the result that, despite the altered innervation, the animal regains, as before, the power of performing voluntary co-ordinated movements of the limb.

2. The fact of crossing the nerves does not add materially to the time which would be required for recovery of function of the limb, if the same nerves were simply divided and reunited by suture as accurately as possible.

3. The result of crossing the nerve supply of antagonistic groups of muscles is that the nerve centres which formerly innervated the one group now serve for the other group, and this alteration extends to the cerebral cortical centres, which become interchanged in position and retain their irritability.

4. The cerebral cortical centres, which have been made to interchange their positions by the crossing, are able in response to the will to emit impulses which can call forth in the new peripheral terminations movements in perfect co-ordination.

5. In man the facial nerve may be detached from the facial centre, attached to the spinal accessory nerve, and the facial muscles thus innervated by the spinal accessory centre, with the result that co-ordinated movements of the face, both voluntary and reflex, are at least in part restored.

6. In the case of reunion of a divided nerve, it is not necessary to suppose that regeneration restores the old paths for the nervous impulses, since, if new paths are formed by the imperfect co-aptation of the divided nerve ends, with the result of altering the connections between central nerve cells and peripheral endings, the organism has the power of compensating this alteration.

7. In the case of paralysis of a muscle or group of muscles, if the nerve supplying the affected muscle or group of muscles is grafted on to a neighbouring efferent nerve supplying muscles which are healthy, it is probable that the affected muscle or group of muscles, if not already destroyed by degenerative process, will regain its normal function.

In conclusion, I have to thank Drs. Brodie and Teacher, of the Glasgow University Physiological Department, Dr. S. Capie, and Dr. J. H. Fullarton, for their kind assistance in the experimental work, more especially in the observations of the results of cerebral stimulation.

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## EXPLANATION OF PLATES.

### PLATE 36.

Fig. 1. Experiment I. Crossing of the Right Musculo-spiral with the Ulnar, Median, and Musculo-cutaneous Nerves. Shows the dog at 161 days after the operation of crossing. The right fore-limb is seen, while still somewhat atrophied, to be used in standing in a perfectly natural manner. The position at the radio-carpal joint is the same in the two fore-limbs. The animal had to be held by the collar, as shown, as its movements were so active that restraint was necessary in order to obtain a photograph.

Fig. 2. Experiment I. Shows the animal at the 93rd day after the operation, with the left leg held up, in order to show that the dog could support the weight of the fore part of its body on the affected leg, and without producing over-extension at the radio-carpal joint.

## PLATE 37.

Fig. 3. Junction of the Peripheral Segment of the Divided Facial Nerve with the Trunk of the Spinal-accessory Nerve for the Treatment of Facial Spasm in a Woman. Shows the patient before the operation. The right side of the face is seen to be contracted in a spasm, as shown by the half-closed eye, the elevation of the angle of the mouth, &c. The muscles were in a condition of tonic spasm ; but at the same time there were incessant twitchings.

Fig. 4. Shows the patient about fifteen months after the operation. The naso-labial sulcus on the affected side is well marked. The photograph was taken by a flash of magnesium light, and the endeavour which the patient was making to keep from winking, betrays the condition of paresis of the right frontalis, which is not able to raise the eyebrow as completely as is the left frontalis. With this exception the face shows no appearance of paralysis.

Fig. 5. Shows the patient about fifteen months after the operation. She is endeavouring to close the eye. The photograph shows that she can do so completely, although not so tightly as in the case of the left eye. The eyelid was not touched, but the patient was simply asked to close her eyes, and the photograph shows the result. Normal furrows caused by muscular contractions are visible on the right side of the chin, and the naso-labial sulcus is well marked.

Fig. 6. Shows the patient at the same date after the operation. The photograph was taken instantaneously, while the patient was in the act of throwing up the right arm. The effect of this action on the right side of the face is shown. The eye is half closed, and the angle of the mouth drawn up, all the muscles being thrown into action. This contraction, however, is present only at the moment of throwing up the arm, passing off immediately, although the arm is continued to be held up.

Fig. 1.

Fig. 2.

Fig. 3

Fig. 4.

Fig. 5.

Fig. 6.